The Evolution of Hydrogeophysics

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While I was involved in petroleum exploration in the late 1980s and early 1990s, I developed a growing conviction that geophysical methods should be useful for quantitative characterization of the shallow subsurface. Although the petroleum industry had been combining wellbore and geophysical data sets for decades to decrease the uncertainty about subsurface properties and structure, I realized that geophysical methods were rarely being used to assist with shallow subsurface investigations.

I approached Ernie Majer at Lawrence Berkeley National Laboratory and voiced my interest in developing methods to permit estimation of hydrological properties using geophysical data. He informed me of the wealth of high-resolution geophysical instrumentation that he had developed, and also about some DOE projects that he was involved in, which involved the acquisition of colocated, shallow subsurface geophysical and hydrological data sets. He asked me to join the effort, and I immediately began to process data sets.

Some of the case studies presented in the 1997 TLE paper were an outcome of that early processing. The concept used in that paper was straightforward. It had been recognized that the velocity of electromagnetic waves in the MHz range, or that of the dielectric constant, was primarily sensitive to water content. Indeed, soil scientists had been capitalizing on that concept when using time-domain reflectometry (TDR) to measure soil water content at the lab and field point scales. I extended this concept for use with field tomographic radar data sets and showed, through comparison of the geophysically obtained estimates and colocated hydrological measurements, what I had suspected: that field geophysical data sets could indeed be used to accurately estimate shallow hydrogeological properties (in this case, water content), and that time-lapse geophysical data could be used to monitor hydrological processes (in this case, water infiltration). Although the approach used for estimation in the TLE paper was simple, it illustrated the potential of geophysical methods for providing estimates of hydrogeological properties and processes in high resolution, in a minimally invasive manner, and at the field scale.

I subsequently developed more advanced integration and estimation approaches, and tested these approaches using DOE hydrological-geophysical field data sets. Others in the community were also publishing successful studies on this topic, and there was a growing recognition that we were onto something exciting and potentially very useful for improving our management of environmental contaminants and water resources. In 2002, I organized a NATO-sponsored workshop in the Czech Republic, intended to bring together for the first time a leading group of international researchers active in hydrogeophysics. I have since heard from several attendees that the meeting was pivotal in the development of the field of hydrogeophysics, because it clearly identified exciting new advances and existing gaps, as well as galvanized the development of a hydrogeophysical community.

Hydrogeophysics has grown enormously since that workshop. It has presence at all significant Earth science professional meetings and is now a subdiscipline in many academic departments. The methods for data integration and property estimation have advanced rapidly in the decade since that *TLE* paper was written. Studies have tackled problems such as nonuniqueness in property estimates, nonstationary data errors, petrophysical relationship uncertainty, and measurement-support scale disparities. Coupled hydrological and geophysical forward-inverse models have been developed to take advantage of complementary observations while honoring hydrogeophysical phenomena. Hydrogeophysical methods have been successfully used to provide effective estimates of many shallow properties and to improve our understanding of shallow subsurface flow and transport. To address your original question: yes, I do believe that the study had an impact and that the field has evolved in a positive direction.

In spite of the advances in the last decade, geophysical methods are not routinely used for shallow subsurface characterization in the way that seismic methods are used in the petroleum industry. There are many research frontiers and there is a huge gap between the state-of-the-research and the state-of-the-practice, which is partially due to the fact that there is not a large financial incentive to deploy these techniques in the shallow subsurface as there is in the petroleum industry. Nevertheless, as safe and effective management of our shallow subsurface resources continues to be a growing challenge facing our society; as wireless sensor, computational, and cyber infrastructure platforms continue to advance; and as hydrogeophysical challenges continue to be tackled, I firmly believe that geophysical methods will eventually become indispensable for shallow subsurface characterization and monitoring.

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